10.0 RI CONCEPTUAL SITE MODEL AND CONCLUSIONS

The CSM for the Portland Harbor Study Area and the RI conclusions are presented in this section.

The objective of the CSM (Section 10.1) is to document our understanding of the sources, and release and fate and transport mechanisms that determine the observed distribution of individual contaminants in affected abiotic and biotic media across the Study Area, based on the information and data collected, compiled, and evaluated in this RI. Section 10.2 then summarizes the major conclusions of the RI report.

10.1 CONCEPTUAL SITE MODEL

This section summarizes the Study Area CSM, including an overview of contaminant distribution, in-river physical environments; site sources; loading, fate, and transport mechanisms; and relevant exposure pathways for human and ecological receptors.

A pictorial representation illustrating the major elements of the CSM (sources, pathways, fate and transport mechanisms, and human and ecological receptors) for the Portland Harbor Study Area is shown in Figure 10.1-1, while Figure 10.1-2 presents a graphical conceptualization of the sources, release mechanisms, transport media, and exposure media of the CSM. The detailed human health and ecological CSMs for the Portland Harbor Site are summarized in Appendix F, Figure 3-1 (also RI Section 8, Figure 8.2-1) and Appendix G, Attachment 2, Figure 1 (also RI Section 9, Figure 9.1), respectively, and focus on exposure routes and receptor groups.

Chemical-specific CSM information for the 13 Indicator contaminants are presented in Sections 10.1.1.2.1 (Nature and Extent) and 10.1.2.4 (Fate and Transport). Each discussion includes a brief presentation of contaminant distribution, potential sources and pathways, and loading, fate, and transport. For each IC, a three-section panel map series is provided that presents cross-media contaminant distributions and available source information . Each panel is an oversized map (24 in. by 36 in.) and presents a subset of the contaminant distribution data. All show the entire Study Area, upland site property boundaries, outfall locations, and river mile markers. The presentation on the panels shows concentrations among proximal samples from other abiotic and biotic media, and known or likely complete source pathways. An electronic version of the three-section CSM panels is included in Appendix I.

Panel A presents summary information on the observed concentration in surface sediment using Thiessen polygons to spatially represent concentrations between data points, sediment traps, riparian soil/sediment, surface water), and TZW from RM 1.9 to 11.8, excluding dredge and cap sample locations. A histogram of the surface sediment data is included in the top left-hand corner of each panel to show the distribution of the data. Unfiltered push probe, filtered push probe, and peeper results are displayed for TZW. Surface water XAD data are presented for total PCBs, dioxins/furans, total DDx, total PAHs, total chlordanes, aldrin, and dieldrin. Surface water peristaltic pump data are presented for arsenic, chromium, copper, zinc, and TBT. The BEHP data presented are a combination of the XAD and peristaltic pump data.

Panel B presents a summary of he subsurface sediment concentrations and large-scale (>30 cm) erosional/depositional areas predicted for a major flood based on the FS HST model for the Study Area (Chen 2011, pers. comm.). Thiessen polygons on these panels represent concentrations in the sediment interval just below the surface sediment (typically the B interval), and the dot on each polygon is color coded to indicate the maximum concentration of the subsurface samples at that location (i.e., this allows for indication of concentrations at depths below the first subsurface interval). A histogram of the subsurface sediment data is included in the top left-hand corner of each panel. Also included are icons depicting the locations of 10 major types of historical industries that are or were active in the Study Area.

In addition to the erosional/depositional information shown on Panel B, Map 10.2-1 shows areas in the Study Area at risk for surface sediment disturbance from incidental anthropogenic activities based on water depth and in-water operations. This includes all areas above the –5 ft NAVD88 contour that are potentially subject to boat wakes, areas in the immediate vicinity of docks and berths, and any additional areas where sediment scour that did not appear to be due to natural forces was evident in the 2002–2009 bathymetric time-series data set.[1] This map does not include an analysis of those activities that are specifically intended to move sediments (shoreline/structure construction, maintenance dredging, or remedial capping/dredging).

Panel C presents whole-body concentrations in field-collected smallmouth bass, clams, crayfish, and sculpin. A detailed view of the composite groupings can be found on Map 2.2-10a–d.

For each upland site that has undergone sufficient investigation to identify known or likely complete pathways, a box is shown on the panels listing the applicable pathways and noting whether they are complete or likely complete. Information used to populate the boxes is based on Table 4.2-2 (source table). Where there are insufficient data to make a determination or when a complete pathway was determined to be not present (see Tables 10.2-1 and 10.2-3 through 10.2-14), no information is presented.

As noted in Section 4.2, the source information presented here is highly dependent upon whether a site is involved in DEQ's cleanup program and the degree of investigation and data generation. As shown on Table 4.2-1, several sites adjacent to or near the Study Area are not in the cleanup program, and it is likely that many sites, particularly those that are the location of historical facilities that operated outside the boundaries of current sites, are not fully addressed in DEQ files. As a result, this section does not represent a complete inventory of sites and operations that contribute or have contributed to contamination in Portland Harbor. These limitations on source

[1] Map 10.2-1 is a qualitative presentation of areas where there is a reason to believe that anthropogenic disturbance risk may be relatively higher than other areas.

information primarily affect historical sources. The understanding of current sources may also be affected by these limitations; however, available information appears to be adequate for the purposes of the FS.

Along with the panels, three figures are provided for each CSM chemical to portray loading, fate, and transport processes under current conditions in the Study Area[2] in a typical year. The first figure consists of a pair of box and whisker plots; the first compares the range of the estimated external and internal annual loads to the Study Area for each of the loading terms quantified for a given CSM contaminant, while the second compares the concentrations of the chemical in surface sediment, sediment traps, and suspended solids in surface water for the entire Study Area. The second figure is a box-and-arrow diagram[3] depicting relevant loading, fate, and transport processes for each CSM chemical at the Study Area scale. The third figure provides a graphical comparison, by river mile, of the quantified external and internal loading terms, including central, upper, and lower estimates, and affords additional resolution of spatial patterns in loading to the Study Area.

As documented in Section 6.1 and Appendix E, external loading of each CSM contaminant to the Study Area was estimated for upstream surface water,[4] stormwater, atmospheric deposition to the water surface, and groundwater advection through subsurface sediments. Estimates were also generated for upland groundwater plumes and permitted point-source discharges for a subset of the CSM contaminants for which these terms may be significant. Unquantified loading terms, including bedload, volatilization, and riverbank erosion, are represented qualitatively on the box-and-arrow diagrams.

The only contaminant fate and transport mechanism internal to the Study Area for which quantitative estimates were developed in the RI is pore water advection from surface sediment to the overlying surface water column. Other internal fate and transport mechanisms, including sediment erosion, sediment deposition, sediment burial, and degradation are represented qualitatively on the box-and-arrow diagrams.

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[2] Includes surface water and bedded sediments in the surface mixed layer (0–40 cm bml).

[3] This diagram does not attempt a mass balance because sufficient data are not available and because of the varying levels of quantification (qualitative to quantitative) of each term.

[4] As discussed in Section 6.1, estimated upstream surface water loads were developed using data from both RM 11 and RM 16. Because of the complex hydrodynamics on the LWR between its confluence with the Columbia River (RM 0) and the entrance to Multnomah Channel at RM 3 (frequent flow reversals, see Section 3.1.3.3), surface water chemical loads leaving the Study Area at RM 1.9 could not be estimated using the simplified approach described in Section 6.1. The furthest downstream surface water loads for the LWR were estimated at RM 4. Surface water loads exiting the Study Area via Multnomah Channel were also estimated.

10.1.1 Nature and Extent

10.1.1.1 Overview of Contaminant Distribution

This section provides a brief overview of the overall distribution of Indicator contaminants in the Study Area sediments, the subsections that follow present CSM data that focus on the distributions of individual Indicator contaminants separately.

Contaminant concentrations in sediment and other media are presented in Panels 10.2-1 through 10.2-15. Sediment concentrations are grouped into concentration ranges based on the data distributions (see Section 5.1.3) and are presented in Thiessen polygons. Based on examination of the contaminant distribution trends shown in the panels (Panels 10.2-1 through 10.2-13), as well as in the Section 5 nature and extent surface and subsurface sediment chemistry maps (Maps 5.1-1 through 5.1-28), some general patterns emerge among subsets of different Indicator contaminants that may be indicative of Study Area fate and transport processes, as well as the relative importance of regional (e.g., upstream) versus Study Area sources. These general patterns are discussed below.

Sediment contaminant concentrations are greatest in nearshore areas: Concentrations of anthropogenic organic contaminants are generally higher in localized nearshore and off-channel areas as compared to sediments in the navigation channel, Multnomah Channel, and downstream areas. In contrast, metals generally exhibit a much narrower concentration range throughout the LWR than the organic compounds.

Contaminant concentrations are generally greater in subsurface sediments: Concentrations of organic contaminants also tend to be higher in subsurface sediments than in surface sediments, but there are chemical-specific and localized exceptions (i.e., subareas where surface concentrations are higher). Of the indicator contaminants, the concentrations of total PCBs, total DDx, total PAHs, total chlordanes, aldrin and dieldrin, and TBT are generally higher in subsurface sediments than in surface sediments, indicating that historical inputs were likely greater than current inputs. In contrast, arsenic, copper, chromium, and zinc do not have large concentration ranges and generally show similar levels in surface and subsurface sediments, although again some local variations in these patterns are present.

Regional inputs exhibit uniform concentrations across the area: Contaminants that may be derived predominantly from regional or upstream inputs show widespread surface sediment distributions without distinct, isolated elevated areas. Examples of this are arsenic and chromium (Panels 10.2-9A–B and 10.2-12A–B), which occur at relatively low concentrations throughout the Study Area, and no strong concentration gradients are apparent.

Areas of high concentrations are present throughout the Study Area and generally are associated with known upland sources: A number of indicator contaminants exhibit relatively high sediment concentrations in distinct areas offshore of known or likely sources. These areas are separated by large areas with relatively lower concentrations lacking obvious concentration gradients. Indicator contaminants that exhibit this general trend include total PCBs, TCDD, BEHP, total chlordanes, copper, zinc, and TBT.

Areas of high concentrations are more common in the lower (downstream) half of the Study Area: Two contaminants, total DDx and total PAHs, exhibit distinct areas of relatively high concentrations at locations in the middle and downstream portions of the Study Area. While there are some small-scale, localized exceptions in the upstream portion of the Study Area, concentrations of both of these contaminants are relatively low outside of these distinct mid-Study Area locations.This pattern is not true for PCBs, which are found in nearshore (outside of the federal navigation channel) and off-channel areas throughout the Study Area that are both more quiescent and proximal to likely or known historical sources.

Concentrations of certain metals are correlated to sediment grain size: A comparison of metals concentrations to the distributions of percent fines in the Study Area shows that where sediments are comprised of less than 40 percent fines, chromium and copper concentrations are relatively low (i.e., above RM 10, between RM 5 and 7, and in the Multnomah Channel; compare Map 3.1-2 with Panels 10.2-12A and 10.2-10A). A similar, but less pronounced, correspondence exists between sandy sediments and zinc concentrations (Panel 10.2-11A).

Sediment contaminant co-occurrence: Several locations within the Study Area have relatively high surface sediment concentrations of more than one indicator contaminant. These areas and the co-occurring contaminants are as follows:

- **RM 9.7W:** total PCBs, dioxins/furans, BEHP, zinc
- **RM 8.7–9.3W:** total PCBs, dioxin/furans, total PAHs, total chlordanes, copper, zinc
- **RM 8.3W:** total PCBs, total PAHs, BEHP, total chlordanes, dieldrin, copper
- **Swan Island Lagoon:** total PCBs, dioxins/furans, total PAHs, BEHP, total chlordanes, copper, zinc, chromium, TBT
- **RM 6.8–7.5W:** dioxins/furans, total DDx
- **RM 6.7–6.8E:** total PCBs, dioxins/furans, copper
- **RM 5.6–5.7E:** dioxins/furans, total PAHs, total chlordanes, copper, zinc, chromium
- **RM 4.3–4.5E:** total PCBs, dioxins/furans, total PAHs, total chlordanes, zinc
- **International Slip:** total PCBs, dioxins/furans, total PAHs, BEHP, total chlordanes, copper, zinc, chromium, TBT.

This degree of contaminant co-occurrence in specific Study Area locations reflects the history of upland site development, including waste and stormwater conveyance systems and industrial and commercial activities, as described in Section 3 and summarized in Section 10.1.2.1 below.

10.1.1.2 Nature and Extent of Indicator Contaminants

This section discusses nature and extent as it relates to specific indicator contaminants.

10.1.1.2.1 PCBs

The Study Area graphical CSM for PCBs is presented on Panels 10.2-1A–C.

PCBs are present at a wide range of concentrations in the Study Area, in all media (Panels 10.2-1A–C). For the purposes of this CSM discussion, PCB concentrations greater than 300 µg/kg in sediment, 100 µg/kg in biota samples, and greater than 400 pg/L in surface water samples are considered elevated (the orange or red symbols and polygons on Panels 10.2-1A–C). The distribution of PCBs is summarized by media below.

Sediments

On a harbor-wide basis, the highest PCB sediment concentrations generally occur in nearshore areas and proximal to local upland sources (Map 5.1-2a–m and Panels 10.2-1A–B). Relatively high concentrations of PCBs are also often found in riparian sediments, sediment trap samples, surface waters, and biota samples in the areas with elevated sediment concentrations. The natural neighbors surface weighted average concentration (SWAC) for PCBs in the Study Area is 85 µg/kg.[5,6] For comparison,the 95 UPL of background total PCB concentrations in the upriver reach of the LWR (RM 15.3 to 28.4) is ## µg/kg dry weight, and the adjusted "OC-equivalent" background 95 UPL of ## µg/kg dry weight was also estimated.

As shown in Figure 5.1-1 and on Panel 10.2-1A, there are several areas with total PCB concentrations above 300 µg/kg in the eastern and western nearshore zones, in Swan Island Lagoon, and in a few scattered areas in the federal navigation channel.Similar spatial and concentration trends are observed for subsurface sediments (Panel 10.2-1A and 10.2-1B). However, the >300 µg/kg surface and subsurface samples are sometimes at different locations (Figures 5.1-1 and 5.1-2 and Panels 10.2-1A–B),Areas where surface and subsurface concentrations are not well correlated may be an indication of spatially and temporally variable inputs and sources, or to different influences from sediment transport mechanisms. The largest areas of where the highest concentrations of elevated PCBs in sediment are observed include the areas offshore of the former

[12] At approximately RM 3, the Columbia River and Multnomah Channel hydraulically influence the flow regime complicating interpretation of load conditions in this area (see Section 3.1.3.3).

[12] At approximately RM 3, the Columbia River and Multnomah Channel hydraulically influence the flow regime complicating interpretation of load conditions in this area (see Section 3.1.3.3).

Albina Shipyard (RM 11.3E), Gunderson (RM 8.89-10W area), Swan Island Lagoon, International Slip (RM 43.7–3.8E), and EOSMRM 2E, and RM 4E.

Total PCB concentrations are generally higher in subsurface sediments (Panels 10.2-1A–B, Maps 5.1-2a–m, and Figure 5.1-33), pointing to predominantly historical total PCB sources and higher past loads. Exceptions to this general trend are noted at RM 11E, Swan Island Lagoon, and Willamette Cove. The area off the Glacier dock (RM 11.3E) was dredged in 2004 and pre-dredging, dredge prism testing identified elevated PCB concentrations. The post-dredging results showed that high PCB concentrations were left at the exposed surface. Dredging also occurred at the CDL Pacific Grain docks (RM 11.4E) in 2002 and 2009, which could also have affected the relationship between surface and subsurface concentrations. The pattern of elevated surface and subsurface sediment levels in this area indicates a local source of PCBs and subsequent anthropogenic sediment disturbance (i.e., prop wash/dredging) which has altered the distribution of PCBs with depth in the sediment column and potentially re-exposed and re-mobilized subsurface contamination.

Collocated surface and subsurface samples from the inner portion of Willamette Cove also show exhibit higher surface PCB concentrations than at depth (Map 5.1-2g). which may be indicative suggesting of higher recent inputs. Finally, in Swan Island Lagoon mean surface and subsurface total PCBs concentrations are approximately the same (Map 5.1-2i)e, based on Figure 5.1-3. 3. Examination of vertical trends on a sample-by-sample basis (Map 5.1-2i) indicates a complex mix of samples exhibiting mostly higher surface levels or similar surface and subsurface levels, but some higher subsurface concentrations also occur. This lack of a clear surface versus subsurface depth-related pattern may reflect a combination of time-varying inputs, low net sedimentation rates, and localized high surface sediment mixing rates that result in variable spatial trends in sediment quality with depth.

Spatial variations in PCB composition (based on congener data) are evident throughout the Study Area, and areas of elevated PCB sediment concentrations often exhibit congener homolog patterns that are distinct from surrounding areas of lower PCB concentrations (Maps 5.1-32 and 5.1-33; Figures 5.1-35a–c and 5.1-36a–c). In general, these areas of lower concentrations are predominated by similar proportions of the tetraCB, pentaCB, hexaCB, and heptaCB homolog groups, with some localized exceptions. Areas of higher concentration (greater than 1,000 µg/kg) tend to be predominated by two or three of these homolog groups and may have a higher proportion of other homolog groups. In the eastern nearshore zone, the overall chlorination level of PCBs in the surface and subsurface sediments tends to be higher at the upstream end of the Study Area and lower downstream. Homolog patterns in areas of high PCB concentration tend to be more variable in the western nearshore zone.

For the areas of elevated concentration noted above, the PCB homolog patterns in surface and subsurface sediment, as well as in the sediment traps and in the particulate portion of the surface water samples, are often similar within each area. Subsurface sediment patterns are less consistent with surface sediment homolog patterns for the areas at RM 6.9 to 7.5W and RM 2.1 to 2.5E compared with the other elevated areas. Also, at RM 6.9 to 7.5W, the surface water and biota homolog patterns had more variations than the homolog patterns across media at the other elevated areas. Across elevated areas, homolog distributions vary spatially between areas, further suggesting multiple sources of PCBs for these areas of elevated concentration.

Relatively low levels of PCBs are widespread in portions of the harbor away from the localized areas of elevated concentrations (Panel 10.2-1A and Map 5.1-1). The histogram inset on Panel 10.2-1A shows that 57 percent of the detected surface sediment results have total PCB concentrations less than or equal to 34 µg/kg; these levels are comparable to the levels measured in the upriver, background reach upstream of Ross Island. The homolog patterns in these widespread, low level PCB areas are generally similar in both depositional and erosional areas, have less distinct variations than areas of higher concentration, and may reflect inputs from upstream and transport within the Study Area.

Water

Relatively high concentrations of PCBs in surface water are generally found in areas with elevated sediment concentrations. The highest total PCB concentrations were associated with single point samples in Willamette Cove and at RM 5.5. These data suggest that local PCB sources may exist in these regions of the Study Area. Total PCB concentrations at RM 11 were consistently higher than at RM 16, suggesting a source or sources between these locations. Aside from these exceptions, the range of total PCB concentrations within the Study Area was fairly consistent.

In the sediment trap data, PCB concentrations were generally higher in samples collected between RM 6.7 and 11.3 compared to other locations.

Aside from large differences in PCB levels in sediment traps between ST007 (RM 11.3E) and its paired location ST008 (RM 11.5W), there was little relative difference in PCB concentrations between other cross-river sample pairs, suggesting suspended sediments are laterally homogenized in most of the Study Area. Total PCB congener concentrations in the Study Area samples were all higher than the average PCB concentrations from upstream locations

GW/TZA

Because of their hydrophobic character, PCBs are not expected to migrate significantly in groundwater. PCBs have been detected in upland groundwater at a few sites, but have not been identified as COIs in groundwater with a complete pathway to the Study Area at any upland sites that were included in the LWG TZW sampling program.

Biota

The high concentrations of PCBs were typically found in biota samples in areas with elevated sediment concentrations. Generally, in areas with elevated surface sediment concentrations, clam, sculpin, and smallmouth bass samples are elevated; however, the crayfish samples are not.

PCBs were detected in all fish samples from the Study Area. PCBs were detected in all invertebrate samples from the Study Area that were analyzed for PCB congeners.

10.1.2 Sources, Physical System, and Fate and Transport

This section provides a brief overview of the sources, migration pathways, physical system, and transport mechanisms in the Study Area. Section 10.1.2.4 presents discussions that focus on the fate and transport of individual Indicator contaminants separately.

10.1.2.1 Sources and Migration Pathways

The following is a summary of information presented in Section 4 on the general nature of historical and current sources and associated pathways to the Study Area.

10.1.2.1.1 Historical

Historical sources dating back to the early 1900s contributed to the majority of the observed contaminant distributions in sediments within the Study Area. This is reflected in the extent and degree of subsurface sediment contamination as discussed in the previous section. Nearly all the identified chemical pathways have an historical component. In the early 1900s, rivers in the United States were generally used as open sewers, which was also true for the Willamette (Carter 2006). Untreated sewage, contaminated stormwater runoff from various land uses, as well as process water from a variety of industries, including slaughterhouses, lumber mills, paper mills, and food processors, was discharged directly into the river, as were pollutants from less conspicuous (non-point) sources, including agricultural fields, oil spills, rubber and oils, and garbage dumps. Manufactured gas operations and bulk fuel storagebegan in the early 1900s while most chemical manufacturing and use began in the 1930s.

Commercial and industrial development in Portland Harbor accelerated prior to World War I and again during World War II. In May 1918, Portland contained 4 steel and 17 wooden shipyards. During the WW II, numerous Liberty and Victory ships, minesweepers, T-2 tankers and other vessels were built at military shipyards located in Portland Harbor. A number of these shipyards were also involved in ship repair and ship conversion. Following the war, many of the ship building facilities closed, but a few were repurposed for scrapping the military’s surplus and obsolete vessels and for ship repair work.

The years following the war saw an increase in industrial development, which continued to spread throughout the Study AreaBrief Summaries of the major industrial operations over the past century. These industrial operations and their associated COIs are provided here:

- **Ship Building, Dismantling, and Repair.** Approximate areas of former shipyards include RM 4E, 5.6E, 7E, 7.4E, Swan Island, RM 9W, 10W, and 11E. Ship building continues at a much smaller scale in Portland Harbor today, with most work focused on ship maintenance and repair. VOCs, SVOCs, PAHs, PCBs, TPH, copper, zinc, chromium, lead, mercury, phthalates, and butyltins are identified as common sediment contaminants associated with shipyards.
- **Wood Products and Wood Treating.** Lumber mills and wood treatment facilities operated at various locations within the Study Area historicallyM&B, a large wood-treating facility, existed at RM 6.9–7.2E. COIs associated with wood treatment include creosote/diesel oil mixtures, PCP, and a variety of water- and ammonia-based solutions containing arsenic, chromium, copper, and zinc (EPA 2006d). PCP wood treatment products routinely contain dioxin/furans as contaminants and these are an additional COI of wood treatment facilities (EPA 2004b). Many other lumber mills and plywood manufacturers were found throughout the Study Area, including Linnton Plywood, St. Johns Lumber (which operated on the present-day Crawford Street and BES WPCL sites), Kingston Lumber, and former mills in Willamette Cove. COIs typically associated with sawmills include metals, TPH, and PAHs. In addition to these COIs, plywood manufacturing could include VOCs and SVOCs, as well as possibly pesticides and fungicides (Eaton et al. 1949; U.S. Forest Service 1964; Moore and Loper 1980; Stellman 1998).
- **Chemical Manufacturing and Distribution.** Study Area chemical plants (RM 6.8–7.5W) that manufacture pesticides and herbicides were in place as early as 1941. COIs typically associated with these operations include pesticides, herbicides, VOCs, dioxins/furans, and metals.
- **Metal Recycling, Production and Fabrication.** Metal salvage and recycling facilities operated at RM 4E, 5.8W, 7.3W (Schnitzer-Doane Lake), 8.5W (Calbag/Acme), 8.9W (Gunderson – Former Schnitzer Steel auto dismantling), and 10W (Calbag) in the Study Area, and several scattered locations upriver . COIs commonly found in waste streams from metal recycling facilities include VOCs, TPH, PCBs, phthalates, cyanide, and a variety of metals. Metal production and fabrication, currently takes place in the Burgard Industrial Park and several sites in the RM 8 to 10.3W reach. COIs associated with metal production and fabrication include metals, PAHs, and TPH. Hydraulic oil with PCBs was often used for high-temperature applications such as die-casting machines. Metal plating also has occurred at a few locations in the Study Area, including Columbia American Plating at RM 9.5W. COIs associated with metal plating activities include VOCs, PAHs, TPH, cyanide, and several metals.
- **Manufactured Gas Production.** Manufactured gas production operations took place between 1913 and 1955 at RM 6.2W. The Pintsch Compressing Company Gas Works at RM 7.3W operated between 1890 and the mid-1930s and manufactured compressed gas from crude oil for railroad train lighting. Prior to 1913, gas production also occurred just upstream of the Study Area at the

Portland MGP site at RM 12.2E. COIs associated with manufactured gas operations include VOCs, SVOCs, TPH, PAHs, metals, and cyanide.

- **Electrical Production and Distribution.** Electrical transformers and capacitors are associated with all of the major industries in the harbor. Some of these transformers and capacitors may contain PCBs. Seven current and one historical substation are found in the Study Area. Transformer repair, servicing, and salvaging operations were found on the east bank from RM 11.3 to 11.5 (Tucker Building, Westinghouse, and PacifiCorp Albina Properties), at RM 3.7W (ACF Industries), RM 9.5E (Portable Equipment Salvage), RM 9.5W (GE Decommissioning), and the GE facility at NW 28th Ave (TSCA site). COIs linked with these types of operations include PAHs, TPH, and PCBs.

- **Bulk Fuel Distribution and Storage and Asphalt Manufacturing.** Bulk fuel facilities have a long history in Portland Harbor. By 1936, most of the facilities currently in place had been established between RM 4 and 8 on the west side of the river. COIs typically associated with bulk fuel storage operations include VOCs, SVOCs, PAHs, TPH, and metals.

- **Steel Mills, Smelters, and Foundries.** The harbor hosted several foundries at RM 11.4W (Gender Machine Works), at RM 9.7W (Schmitt Forge), and at RM 2.7E (Consolidated Metco). Several smelters were located at RM 7.2W (Gould), at RM 9W (National Lead/Magnus Smelter), and at RM 11.6W (RiverTec Property). Steel mills are or were located at RM 2.4E (Evraz, aka Oregon Steel Mill) and at RM 8.3W (former Oregon Steel Mill operation at Front Ave LP). COIs associated with these types of operations include metals, TPH, PCBs, and PAHs. PCBs were a component of hydraulic fluid for high temperature applications (machining and die casting) where fire resistance was important, and were also a component of heat transfer fluid used in applications like heat exchangers and recirculating cooling systems.

- **Commodities Maritime Shipping and Associated Marine Operations.** In addition to the Port of Portland's large presence in Portland Harbor with three deep-water terminals committed to import/export, currently there are or have been several other commodity shipping facilities in the harbor. These include the grain handling operations at CDL Pacific Grain (RM 11.4E) and Centennial Mills (RM 11.3W), edible oils at the former Premier Edible Oils facility (RM 3.6E), scrap metal export at International Terminals (RM 3.7E), cement import and distribution at Glacier NW (RM 11.3E), anhydrous ammonia and solid and granular urea at JR Simplot in the South Rivergate Industrial Park (RM 3E), and alumina, electrode binder pitch, and grain at the former Goldendale Aluminum property (RM 10E). Supporting maritime activities include over-water tug and barge moorage, maintenance and repair facilities, overwater bunkering and lightering, tug-assisted and independent maneuvering of vessels in and around marine facilities, and stevedoring (loading and discharging) product at vessels. Incidental spills into the river from commodities maritime shipping include organic materials, VOCs, PAHs, and TPH.

- **Rail Yards.** The Study Area has hosted several types of rail yard and freight car repair operations. Active facilities are located at approximately RM 9.8 to 11.1E (UPRR Albina Yard), RM 8.6 to 9.5W (PTRR Guilds Lake Yard), and RM 4.8E (UPRR – St. Johns Tank Farm). Historical rail yard operations were located at and around RM 11.6W (BNSF Hoyt Street Railyard, and UPRR Union Station operations). Historical rail car maintenance operations were located at RM 3.6 (ACF Industries). At rail yards used for fueling or rail car maintenance, COIs may include VOCs, SVOCs, TPH, PCBs, and metals. Railcar switching yards (RM 8.1W BNSF Willbridge Switching Yard) are locations where trains are assembled and disassembled, and this moving of railcars typically does not result in releases or produce waste streams.

COIs related to these facilities and operations reach the in-water Portland Harbor media through several migration pathways, including stormwater, industrial wastewater, overland flow, groundwater, bank erosion, and overwater releases. COIs associated with these pathways are typically related to site-specific operations, but in the case of shared stormwater conveyance systems, COIs may be associated with a number of facilities.

Some contaminated surface soils exposed in the upland areas and along riverbanks can be carried directly to the river as riverbank erosion and in stormwater sheet runoff (i.e., overland transport). The greatest erosional events occur during high flows and floods. As development continued through the 1900s, the bank was armored in many areas. The occurrence and relative importance of riverbank contamination is not well characterized for all parts of the Study Area, but it is a focus of DEQ's Joint Source Control investigations. Contamination in riverbank soils can result from upland activities or from contaminated material used in construction fill activities. In some locations, contaminated dredged material may have been placed in low-lying areas subject to erosion. While the quality of this fill material is generally undocumented, the time periods involved and the history of sediment contamination from a range of industrial and maritime sources suggest that contaminated sediment could have been included in the fill material. Bank erosion and overland transport of soil to the river were likely more important historically, prior to the development of extensive stormwater conveyance systems and paving of upland areas adjacent to the Study Area.

Migration of contaminants from upland areas to the river via the groundwater pathway is also a historical source of contamination to the river at a limited number of upland sites within the Study Area based on available information. At a subset of these sites, the historical groundwater pathway has contributed significant loads of upland contaminants to sediment and TZW. While some complete historical groundwater transport pathways have been mitigated or eliminated through source control actions, others remain complete, as identified in the following section.

Historically, overwater releases were common occurrences for industries on the banks of the Willamette that relied on maritime shipping to get commodities to and from market. Overwater releases are likely important historical contributors to in-water contamination at sites that have long histories of overwater operations (e.g., ship building and repair, dock facilities, fuel facilities) and product transfers. However, as noted in the section below, records of overwater spills over the past 30 years generally do not include documentation of large releases.

Upstream sources also contributed to the historical contamination of the LWR. These sources included sewerage, stormwater runoff, and direct discharge of industrial wastes from upstream cities, towns, and industrial areas; agricultural runoff; and aerial deposition on the water surface and drainage areas within the Willamette Valley.

10.1.2.1.2 Current

Many of the large historical operations in the harbor have ceased operating over the past 50 years. These former operations include widespread ship building and scrapping operations; large-scale chemical manufacturing; manufactured gas production and wood treatment; and the manufacturing, repair, and storage of PCB-containing electrical equipment. However, some historical operations continue to exist today, including bulk fuel storage, barge building, ship repair, automobile scrapping, recycling, steel manufacturing, cement manufacturing, transformer reconditioning, operation and repair of electrical transformers (including electrical substations), and many smaller industrial operations. Maps 3.2-3 through 3.2-12 show the locations of both current and historical major industrial operations in Portland Harbor.

Stormwater and wastewater discharges are regulated and permitted for many of the sites adjacent to the Study Area. However, sampling for RI-related chemicals in stormwater and catch basins only began in recent years and, for the most part, has only been done for those facilities that have voluntarily conducted a JSCS stormwater source control evaluation. In addition, under the 2003 Intergovernmental Agreement between DEQ and the City, the City is continuing through storm drain sampling to identify sites discharging RI-related chemicals to the Study Area. Significant examples of the City's work under its Portland Harbor Program are the identification of the GE Decommissioning and the Calbag-Nicolai sites as PCB sources to stormwater. Known or likely complete pathways for stormwater have been identified at many sites (see Section 4). As continued sampling is conducted under the JSCS and City programs, additional sites with known problematic stormwater discharges may be identified.

With the construction of stormwater treatment systems and wastewater treatment systems over the years, overland transport has been largely abated at most sites. A current overland transport pathway has been identified as likely complete at very few sites, although more such sites may continue to be discovered.

With respect to the groundwater pathway, available groundwater information for more than 120 upland sites bordering and/or in close proximity to the river was reviewed during the RI and under JSCS programs. Based on this data review, and on further sampling information collected and evaluated during the RI groundwater pathway assessment, current known complete or likely complete pathways have been identified for 11 sites, 51 sites have insufficient data to make a determination, and 58 sites have been identified as not having a complete pathway. The groundwater pathway assessment conducted during the RI developed detailed groundwater discharge and TZW sampling information at nine high priority sites. Based on these efforts, a current complete groundwater pathway with influence on TZW and sediment chemistry was confirmed at four sites, migration of groundwater was found to have no significant influence on TZW and sediment chemistry at four other sites, and the effect of upland groundwater on TZW and sediment chemistry could not be established at one site (see Appendix C2).

Riverbank erosion from contaminated and unstabilized bank areas may represent an ongoing release mechanism in the Study Area. Currently about 75 percent of the riverbanks within the Study Area are stabilized and armored with various materials, including seawalls, riprap, and engineered and non-engineered soil. Known or likely complete riverbank pathways have been identified at a few sites with unstabilized banks, although more such sites may continue to be discovered. The occurrence and relative importance of riverbank contamination is a focus of DEQ's JSCS investigations.

The activities most commonly associated with current overwater spills in the Study Area are product handling, overwater activities such as refueling, and spills from vessels. Overwater releases are likely important contributors to in-water contamination at sites that have long histories of overwater operations and product transfers. Spill records collected over the past approximately 30 years do not generally record large releases, but there have been some exceptions.

DEQ's JSCS program focuses on the abatement of current and threatened future releases of contaminants to the Study Area. The current status of that program is summarized in Section 4.6.

As with historical sources, current upriver sources also play a role in the contaminant distribution in the LWR. Current upstream loading is discussed in section 10.1.2.3.1.

10.1.2.2 Physical System

The Portland Harbor RI/FS Study Area (RM 1.9 to 11.8 of the Willamette River) is located at the downstream end of the LWR, which extends from the Willamette Falls at RM 26 to its convergence with Columbia River at RM 0. In its natural, undisturbed state, the Study Area reach was a relatively shallow, meandering portion of the LWR, surrounded by uplands, forested wetlands, and floodplains. As the Portland Harbor was developed as a shipping harbor over the last century, the channel has been redirected, dredged, and straightened. Nearshore and riparian areas have been filled, channelized, and modified with flood and erosion control measures to allow industrial development of uplands adjacent to the harbor.

Much of the original riverbank has been filled, stabilized, and/or engineered for commercial, industrial, and marine operations with riprap, bulkheads, and overwater piers and docks. Currently, a federal navigation channel authorized to –43 ft CRD but maintained to –40 ft CRD, approximately double the depth of the natural riverbed, runs to RM 11.6, nearly the entire length of the Study Area. In some locations of the Study Area, the navigation channel extends nearly bank-to-bank, resulting in an altered river cross section. The extensive physical alteration and the associated anthropogenic activities as well as upstream river-stage control through the construction and management of dams, have resulted in a river reach that little resembles its pre-industrialized character in terms of hydrodynamics, sediment processes, and ecological habitat.

10.1.2.2.1 Flow Regimes, Hydrodynamics, and Sedimentation

The Willamette River is the thirteenth largest river in the contiguous United States in terms of discharge, averaging about 40,000 cfs. Flows are highly variable, however, both seasonally and year-to-year as a function of rain and snowpack levels in the region. Discharge typically varies seasonally by a factor of 10, with late-summer, dry-season levels at or below 10,000 cfs and rainy season December/January averages that approach and periodically exceed 100,000 cfs. Thirteen federal dam/reservoir systems on the upper Willamette River and its tributaries are used to stabilize river flow by storing water in the winter months and releasing it in the summer. Nonetheless, discharge events approaching 200,000 cfs occur every few years, and exceptionally large precipitation and snow melt events can still result in major floods.This combination of river regulation, high seasonal flow variability, and high levels of anthropogenic activity within the Study Area results in potentially complex and variable sediment transport dynamics over time.

The Study Area is a relatively low-energy, depositional reach of the LWR. The upstream portion of the LWR is markedly narrower and more confined by bedrock outcrops, and faster flowing than the Portland Harbor reach. Immediately downstream of the Study Area, the river narrows as it turns and converges with the Columbia. Multnomah Channel exits at RM 3, considerably reducing discharge downstream of that point. This physical setting and the associated hydrodynamic interactions result in deposition and accumulation of some of the suspended, and most of the bedload, sediments that enter the Study Area from upstream over time.

Within the Study Area, there are distinct reaches that share similar hydrodynamic characteristics (see Section 3.1.5). The primary factors controlling river flow dynamics and riverbed character appear to be the river cross-sectional area and navigation channel width. Relatively long-term net sedimentation rates can be estimated for the Study Area based on empirical information. Measured riverbed elevation changes over the seven-year period from 2002 to 2009 illustrates a pattern of general shoaling in the reaches from RM 7 to 10 and RM 2 to 5 and no change or scour in the higher energy reaches upstream of RM 10, and between RM 5 and 7. The maximum net sedimentation accumulation occurs in the navigation channel between RM 9 and 10 and in the upstream borrow pits at RM 10.9 and 10.5. Maximum sedimentation rates over the seven-year period approach and, in some places, exceed 30 cm/yr in these areas.

Shoaling on a similar scale along the western half of the navigation channel from RM 8 to 10 is evident from the 2002 to 2009 bathymetric change data set (e.g., a maximum accumulation rate of 31 cm/yr on the shoal at RM 9.6); this area has historically required regular maintenance dredging. Bathymetric change data from 2002 to 2009 in the downstream channel shoaling area, which begins at RM 2.8 and extends downstream towards the confluence with the Columbia River, showed a maximum sediment rate of about 18 cm/yr at RM 2 over this seven-year time frame. The decrease in net sedimentation rates between upstream and downstream channel shoaling areas is consistent with a single major source of sediments (both suspended sediments and bedload sediments) that enter the Study Area from upstream and then settle out or are trapped in depressions and shoaling areas from upstream to downstream.

Estimates of net sedimentation rates for nearshore (i.e., shoreward of the federal navigation channel) and off-channel areas in the Study Area (e.g., Swan Island Lagoon) are based on bathymetric change data, SPI observations (SEA 2002b), and limited radioisotope sampling for MNR assessment (Anchor 2005). These data indicate that sediments do not accumulate in nearshore areas at the rates noted above for the major shoals in the channel environment. While many nearshore areas exhibit fine-grained sediments and appear to be depositional (e.g., based on SPI interpretation), little net elevation change and/or small-scale scour was observed in many nearshore areas, such as RM 9 to 11E, areas within Swan Island Lagoon and Willamette Cove, RM 6.5 to 7.5W, and RM 5 to 6.5E from 2002 to 2009. Short-term active surface sediment mixing is also suggested by these data sets; this may be due to anthropogenic disturbance factors in many areas of the working harbor. These observations from the bathymetric and SPI survey data are supported by the radioisotope data from four nearshore areas collected in 2004 in water depths of –4 to –28 ft NAVD88, which showed well-mixed surface sediment layers and calculated net sedimentation rates of approximately 1 cm/yr.

In summary, based on the seven-year bathymetric change data, most of the channel and off-channel areas appear to accumulate sediment or show minimal change over time. While most nearshore areas appear to be depositional environments, some areas seem to be subject to frequent disturbance and sediment resuspension. Net sedimentation rates in nearshore areas appear to be relatively low. The revised FS HST model suggests that during extreme events, such as the 1996 flood, relatively deep (to two meters) scour occurs only in the sandier, high-energy, in-channel reaches. The remainder of the Study Area stays relatively stable or continues to accumulate sediments. This is consistent with the overview of contaminant distribution noted above in which the highest concentrations of most anthropogenic contaminants are observed in stable, subsurface sediments adjaceent to known or likely upland sources of those contaminants.

10.1.2.3 Fate and Transport

The boundaries of the Study Area include the upstream and downstream river mile designations (RM 11.8 and 1.9), the surface of the river, the riverbank sediment/riparian soil boundary at an elevation of +13 ft NAVD88, and the surface sediment/subsurface sediment boundary at 30 cm bml. Contaminant mass passing through these boundaries into the Study Area are external loads. External loads include upstream loading via surface water and sediment bedload, stormwater, permitted industrial discharges, upland groundwater transport, atmospheric deposition, direct upland soil and riverbank erosion, groundwater advection through subsurface sediments (partitioning and advection from subsurface to surface sediment), and overwater releases. Many of these external loading terms have been quantified for the CSM Indicator contaminants and so their relative magnitudes can be compared.

Internal transfer mechanisms are those that involve the transport of contaminant mass from one media to another within the Study Area as defined above, but which do not add new contaminant mass to the Study Area. Internal fate and transport mechanisms include sediment resuspension, transport, and deposition, solid/aqueous-phase partitioning, abiotic/biotic transformation and degradation, biological uptake and depuration, and partitioning from surface sediment to surface water. Groundwater advection is the only internal process that is quantified here. Some internal processes may be significant in the transfer of contaminants between abiotic media and biota (e.g., sediment resuspension) and may be quantified as part of the FS fate and transport modeling effort.

10.1.2.3.1 External Loading Mechanisms

The generally higher contaminant concentrations in subsurface sediments throughout much of the Study Area, particularly in nearshore areas that appear to be long-term depositional/stable sedimentary environments, indicate that historical sources were significant contributors to the contaminant concentrations measured in Portland Harbor sediments However, understanding ongoing sources and their associated contaminant loads to the Study Area is important in assessing recontamination potential, identifying the need for source control activities, and evaluating remedial technologies in the FS. Identification and control of current sources is being implemented by DEQ through the JSCS program. Estimated *external* contaminant loads from current sources to the Study Area are summarized below .[7] Current contaminant loading to the Study Area includes the following:

- Upstream inflows of water and sediment
- Stormwater and CSO discharges from upland areas
- Direct permitted discharges

[12] At approximately RM 3, the Columbia River and Multnomah Channel hydraulically influence the flow regime complicating interpretation of load conditions in this area (see Section 3.1.3.3).

- Atmospheric deposition
- Upland groundwater
- Groundwater advection through sediments (partitioning from deep sediment, advecting to shallow sediments)
- Upland soil and riverbank erosion (qualitative)
- Overwater releases from ongoing activities (qualitative).

It should be noted that the empirical loads reported in the RI are based on measurements, e.g., upstream surface water concentrations, collected over the range of flows experienced during the RI sampling period. While every effort was made to capture a full range of seasonal flow levels (i.e., less than 10,000 to 168,000 cfs) as described in Section 5.3, no empirical data from extreme or flood conditions were collected. This adds some uncertainty to the empirical loading estimates. For all loading terms, the target loading units are mass per year to the entire Study Area for a typical water year. Each estimate of current loading has a corresponding historical component that may be significant to the current contamination profile in the Study Area. Historical loading is expected to have occurred by all loading mechanisms; however, very limited quantitative data are available to support estimates of these historical terms. For many locations and contaminants, historical loading is likely to have been higher than current conditions due to environmental regulations and controls that have been implemented in recent decades . .

Upstream Loading

Upstream loading represents the largest current loading term for the Study Area. While upstream surface water and suspended sediment concentrations are typically lower than those measured in the Study Area, the very large flow volume of the river compared to the flow volumes for the other loading terms results in a relatively large mass load of contaminants compared to other current sources. Figure 10.1-3 shows estimated flow volumes used for the various loading terms. Upstream loading is defined as the contaminant mass that entered and continues to enter the Study Area via dissolved and suspended particulate transport mechanisms. Upstream loading includes surface water loading (dissolved and suspended solids fractions) and was assessed quantitatively.[8]

This loading exceeds other source by 1 to 3 orders of magnitude for all of the CSM Indicator contaminants, with the exception of total PAHs and TBT, for which mass loading estimates via groundwater advection through surface sediment are comparable with the mass input via surface water.

Stormwater Loading

Based on the stormwater loading calculations current stormwater runoff is the second largest quantified annual external loading term to the Study Area for all CSM Indicator

[12] At approximately RM 3, the Columbia River and Multnomah Channel hydraulically influence the flow regime complicating interpretation of load conditions in this area (see Section 3.1.3.3).

contaminants, with the exceptions of total PAHs (current stormwater runoff is the lowest loading term) and arsenic (stormwater is the fourth highest loading term).[9] It is expected that the overall contribution of stormwater loading to the Study Area may have been more significant historically, prior to implementation of current management practices and stormwater runoff controls. Loading from CSO discharges is also a factor in stormwater loading, however, at a much reduced rate than in the past.

Stormwater is a migration pathway for contaminants in upland areas to reach the river via runoff from the local watershed. Contaminants present in stormwater runoff may be present in the upland watershed as a result of upland soil contamination, atmospheric deposition, and a wide range of anthropogenic activities. Stormwater-related chemicals are transported mostly via conveyance systems and discharged through numerous outfalls along the river shoreline within the Study Area. Overland flow of stormwater to the river also occurs in some relatively limited areas.

The estimated stormwater annual load is generally highest for the heavy industrial land use category and individual (non-representative) industrial sites as compared to the other land uses, which include light industrial, parks/open space, residential, and major transportation (see Tables 6.1-5a and b). ForPCBs and DDx, the individual non-representative industrial outfalls contribute over half of the total stormwater load to the Study Area. For PAHs, the heavy industrial land use category is also the dominant load, but the light industrial and the major transportation land use category also are important (i.e., about 20 percent of the total estimated composite water load, combined). Individual non-representative industrial outfalls contribute about half of the total PAH stormwater load to the Study Area. PCDD/Fs were not measured in stormwater. Among the other CSM Indicator contaminants, the heavy industrial category also dominates loading from representative land use types, followed by light industrial, with minor contributions from all other categories for the metals.

For total PCBs, the annual estimated load via stormwater is about one half of the upstream surface water load. For the remaining CSM Indicator contaminants, estimated loads from stormwater to the Study Area are typically 1 to 2 orders of magnitude lower than upstream surface water loads.

Direct Permitted Non-Stormwater Discharges

NPDES-permitted, non-stormwater discharges to the Study Area include private and municipal outfalls. Current annual load estimates for this source term were generated for the 14 NPDES wastewater permitted discharges in the Study Area listed as either Individual or GEN 15A Permits. Semi-quantitative annual loads were estimated from discharge and flow data in Discharge Monitoring Reports for the 10 dischargers with available information for CSM Indicator contaminants. Of the CSM Indicator

[12] At approximately RM 3, the Columbia River and Multnomah Channel hydraulically influence the flow regime complicating interpretation of load conditions in this area (see Section 3.1.3.3).

contaminants, analytical data for only total PAHs, arsenic, chromium, copper, and zinc were generated as part of the permits.

Overall, it is expected that loading via permitted non-stormwater discharges, as defined and assessed here, is not currently a major source of CSM Indicator contaminants to the Study Area since it represents regulated and monitored loads. This is supported by the chemicals for which there are data (PAHs and metals) where the annual estimated loads via permitted discharges are 2 to several orders of magnitude smaller than upstream surface water loads.

Historical loading to the Study Area from industrial discharges, however, was likely more significant prior to adoption and implementation of laws and regulations for discharge permits and controls.

Atmospheric Deposition Loading

Current atmospheric deposition to the Study Area (the sum of wet and dry deposition) was estimated semi-quantitatively using a literature-based deposition velocity and, depending on the chemical, local or non-local air and precipitation chemical concentrations. For most CSM Indicator contaminants, local atmospheric concentration data and/or precipitation concentration data were limited or could not be found; therefore, these loading term estimates are considered more uncertain than semi-quantitative loading estimates for other loading terms. Total atmospheric deposition could not be estimated for BEHP or TBT due to lack of applicable local or literature values. The atmospheric deposition loading analysis results are discussed on a chemical-specific basis in Section 10.1.2.4.

For total PCBs, TCDD TEQdioxins/furans, total PAHs, and total DDx, annual estimated loads via atmospheric deposition are 1 to 2 orders of magnitude smaller than upstream surface water loads. For the remaining CSM Indicator contaminants, estimated loads from atmospheric deposition to the Study Area are typically 2 to 4 orders of magnitude lower than upstream surface water loads.

It is likely that overall atmospheric loading to the Study Area for PCBs and DDx pesticides was more significant historically, prior to widespread adoption of controls by many countries on chemical production and usage. For these contaminants, the atmospheric concentrations of these now-banned and/or controlled substances have decreased relative to historical levels; however, they are still present in the atmosphere.

Upland Groundwater Plume Loading

Upland groundwater plume loading is defined as the current contaminant mass entering the Study Area transition zone/surface water via upland groundwater plumes flowing toward the river. Empirical seepage rate and TZW concentration data from the nine

GWPA study sites were applied to generate quantitative annual loads.[10] Because contaminant concentrations in TZW may include contributions from sources other than just upland plumes (e.g., desorption from contaminated sediment), this approach for calculating upland plume loads may result in overestimates.Of the 13 CSM Indicator contaminants, upland groundwater plume loading was assessed for only total DDx, total PAHs, arsenic, copper, and zinc. The other CSM Indicator contaminants were not identified as having a known or likely complete pathway from upland groundwater to the river; therefore, they were not sampled in transition zone water. The upland groundwater plume loading analysis results are discussed on a chemical-specific basis in Section 10.1.2.4.

Of the five CSM indicator contaminants sampled in groundwater, upland groundwater plume loading from the nine TZW sites appears to significantly contribute to the overall Study Area external loading for only total PAHs. On a localized basis, however, this loading term is relevant compared to other external loading terms for total DDx, total PAHs, arsenic, chromium, copper, and zinc (discussed further in Section 10.2). For total PAHs, annual estimated loads via upland plumes are approximately one-half of the upstream surface water load. For the remaining CSM indicator contaminants for which loads were estimated, the loads from upland plumes to the Study Area are typically 2 to 3 orders of magnitude lower than upstream surface water loads.

It is possible that groundwater plume loading to the transition zone was more significant historically. However, the time delay in transport of chemicals from upland groundwater to the river can be significant, making it difficult to predict or generalize about the duration of migration or the timing of the peak concentrations in the transition zone.

Groundwater Advection through Sediment Loading

Subsurface advective loading refers to the migration of chemicals associated with subsurface sediments to shallow surface sediments via desorption and groundwater advection. This term was assessed semi-quantitatively from the surface sediment concentration data set by applying an assumption of equilibrium partitioning and a uniform groundwater flux. The range of values presented for sediment advective loading demonstrates the uncertainty associated with these estimates based on the large range of equilibrium partitioning constants available in the literature. The groundwater advection loading analysis results are discussed on a chemical-specific basis in Section 10.1.2.4.

Except for total PAHs and TBT, the results indicate that groundwater advection through surface sediment is not a significant loading term compared to other loading terms for the CSM indicator contaminants (e.g., one to several orders of magnitude lower than the upstream surface water loads). Advective loading of total PAHs is comparable in

[12] At approximately RM 3, the Columbia River and Multnomah Channel hydraulically influence the flow regime complicating interpretation of load conditions in this area (see Section 3.1.3.3).

magnitude to upstream surface water and upland groundwater plume loading terms, and is dominated by the LPAH fraction. For TBT, loading was estimated for only the upstream surface water and sediment advective loading; the advective loading estimate was slightly higher but comparable to the upstream surface water loading estimate.

The relative historical advective loading from subsurface sediments to surface sediments is uncertain; however, the patterns in sediment concentration with depth provide some insight. For PCBs, DDx, and PAHs, subsurface sediment concentrations exceed surface sediment concentrations in most of the Study Area, suggesting that these compounds were released in greater amounts in the past and subsequently covered with lower concentration sediments. Higher shallow subsurface sediment concentrations in the past would result in greater subsurface advective loading to past surface sediment horizons.

Upland Soil and Riverbank Erosion Loading

Erosion of bank soils is a potential source of chemicals to the Study Area. Although it is estimated that approximately 15 to 25 percent of the banks within the Study Area are potentially vulnerable to erosion (i.e., they are not stabilized or armored), it is not possible to estimate erosion rates or a range of rates that might apply to these areas given the wide range of conditions present. Further, bank soil chemistry data are extremely limited and not suitable for extrapolation to the Study Area because an erodible bank soil may not be a source of CSM indicator contaminants. Consequently, current bank soil loading estimates could not be developed and could not be assessed relative to other loading terms.

Because bank erosion is a location-specific condition dependent on both the erodibility of and contaminant concentrations in the bank area, the potential role of bank erosion below mean high water level may need to be evaluated as a part of the remedial design process for each SMA. DEQ is actively addressing cleanup of many upland sites adjacent to the river, and erodible banks above mean high water level are being evaluated under the DEQ's Joint Source Control program.

Overwater Releases

The activities most commonly associated with current spills in the Study Area are product handling, overwater activities such as bunkering (overwater fueling), lightering and vessel repair and maintenance, and vessel spills and leaks. All sites with active overwater facilities have the potential for releases to the river. Spill records collected over the past approximately 30 years do not generally include records of large releases, but there have been some exceptions.

Contaminant releases from current and/or historical overwater activities (e.g., sandblasting, paint removal and painting, material transfer, bunkering, maintenance, repair, and operations at riverside docks, wharfs, or piers), discharges from vessels (e.g., gray, bilge, or ballast water), fuel releases, and spills are not considered quantifiable and were not specifically assessed in the loading analysis. However, historical releases of this nature are important in the overall CSM because these releases are believed to be a potentially significant source of the existing contamination in some locations in the Study Area, especially in the deeper sediments. While improved BMPs are likely to have reduced the occurrence of overwater releases significantly, it is acknowledged that current and future releases could occur.

10.1.2.3.2 Internal Fate and Transport Processes

Once a chemical enters the Study Area it may be transported or transformed by physical, chemical, and biological processes that occur within the Study Area. Identifying these fate and transport processes in the CSM is important because it provides a framework for assessing critical issues such as the following:

- Significance of current external loads in regards to recontamination
- Erosion/resuspension and movement of contaminated sediments within the site
- Transport of contaminants from buried deep sediments to biologically active sediments and pore water
- Partitioning of contaminants between sediments and surface water and the impact of contaminants in one media on the quality of another media
- Transformation by biotic and abiotic processes to contaminants that may be more or less toxic
- Bioavailability and uptake of contaminants into biota.

A brief description of important site elements and how they may affect contaminant distribution and site risks is presented below.

Solid/Aqueous Partitioning

The transport, degradability, and bioavailability of a contaminant often relates to its tendency to associate with particulate material within the system. Many of the CSM indicator contaminants are hydrophobic organic compounds, which tend to partition preferentially to the dissolved and particulate organic matter associated with the solid and aqueous phases of surface water, sediments, and pore water. Because the particulate organic matter within the solid phase of sediments represents the largest available pool of organic carbon in the Study Area, contaminated sediments represent the largest repository (by mass) of CSM indicator contaminants of all environmental matrices addressed by this RI.

Surface Water/Sediment Physical Transport

The flow of river water is the primary mechanism for transport of dissolved and particle-bound chemicals. Lateral and vertical movement of chemicals in surface water occurs primarily as a result of turbulent (eddy) dispersion (mechanical mixing). Higher flow velocities typically cause greater mixing and increased transport of suspended and bedload sediments. With the exception of the channel environment upstream of RM 10 and between RM 5 and 7, the Study Area appears to be a depositional or relatively stable sedimentary environment.

Relevant processes that influence sediment transport include deposition, erosion/resuspension, mixed-layer turbation, long-term burial, and ingestion/uptake by biota. A potentially important mass transfer mechanism is surface sediment resuspension and movement of contaminants from bedded sediment to the water column with a resultant increase in mobility and bioavailability.

Abiotic and Biotic Transformation/Degradation

A variety of abiotic and biotic (microbially mediated) degradation processes are relevant for transformation and degradation of indicator contaminants in Study Area aerobic and anaerobic sediments. Relevant abiotic degradation/transformation/loss mechanisms include abiotic oxidation/reduction, hydrolysis, dehalogenation (e.g., reductive dechlorination), volatilization (primarily from dissolved phase in surface water), and photolysis (primarily in upper levels of surface water). Microbially mediated degradation (biodegradation) involves the metabolic oxidation or reduction of organic compounds.

Uptake into Biota

A number of processes govern how organisms living in the Study Area are exposed to contaminants and how contaminants are transformed, excreted, or stored in tissue. Organisms living in the Study Area may take up (bioaccumulate) contaminants through physical (e.g., diffusion), chemical, and biological processes, including transfer of water-borne contaminants across gill structures or other tissues, consumption of prey, or ingestion of sediment.

10.1.2.4 Sources, Fate and Transport of Indicator Contaminants

This section discusses sources, fate and transport as it relates to specific indicator contaminants. Point and non-point sources from within the Study Area and upstream of the Study Area have contributed to the sediment contaminant distributions detailed in Section 5 for the 36 nature and extent indicator contaminants and are summarized briefly here for the 13 indicator contaminants selected for the CSM.

10.1.2.4.1 PCBs

PCB Sources and Pathways

Numerous upland sites have been identified as being known or likely historical and/or current sources of PCBs. These sites discharge directly to the river or discharge through shared conveyance systems (Table 4.4-1). Historical and current known or likely complete pathways for PCBs in stormwater have been identified at several properties associated with former shipyards and sites where transformers were serviced and/or dismantled. Historical wastewater discharges associated with ship building and decommissioning, electrical component manufacturing, and leaks and spills from equipment that used PCBs (e.g., hydraulic oils) are likely, but have not been specifically identified or quantified. Wastewater discharges are currently regulated primarily through NPDES permits.

Potential upland and overwater sources and identified known and likely complete migration pathways are identified on Table 10.2-1 and Panels 10.2-1A–C. These sources and pathways, identified on the basis of the process described in Section 4.2, focus on ECSI sites and are based on a review of information in the associated DEQ ECSI files and other readily available site information, including, in the case of LWG-member sites, information provided by the site owner.

The most significant migration pathways for PCBs in the Study Area are historical and included industrial wastewater, stormwater, overland transport, overwater releases, and riverbank erosion (Table 10.2-1). Atmospheric deposition and upstream inputs may have also contributed PCBs to the Study Area, the releases from these pathways are not quantifiable and are difficult to distinguish.

Stormwater PCB loads have decreased substantially from historical levels since implementation of stormwater controls and the statutory ban on PCB manufacture in the 1970s. Overland transport was likely more important prior to the development of extensive stormwater conveyance systems. Bank erosion is also likely more important when PCBs were in wider use, or when contaminated material was used in construction fill activities. Historical PCB overwater releases have not been identified through the file review process, but are likely to have occurred in association with overwater operations, such as ship building and dismantling, ship repair and maintenance, and with the use of hydraulic fluids in dock operations. The locations of elevated PCB concentrations in sediments coincide in some cases with historicalship construction, dismantling, and repair operations, and it is likely that overwater releases occurred concurrently as a result of historical activities in these locations. PCBs are also detected in sediments near outfalls draining facilities historically engaged in electrical equipment manufacturing, such as at RM 11.3E and at OF-17. Stormwater discharges and riverbank erosion associated with fill soil from offsite and/or steel manufacturing activities at RM 2E have also resulted in PCB contamination in sediments.

Current PCB inputs to the Study Area are much lower than historical inputs. However, measured elevated levels of PCB concentrations in surface sediments and other media, including biota in the International Slip and Swan Island Lagoon indicate ongoing localized inputs and/or internal mass transfer of historical PCB inventory from subsurface to surface sediments and then to other media by processes such as sediment resuspension (due to both natural and anthropogenic disturbance factors) and biological uptake. While surface sediments generally exhibit lower PCB concentrations than subsurface sediments, the temporal persistence of elevated PCB levels in surface sediments in many nearshore and off-channel areas suggests that net sedimentation rates may be low in many nearshore areas. This is supported by the bathymetric change data and the limited radioisotope data from the Study Area (Anchor 2005), sediment column mixing rates are high, and inputs of PCBs still occur. Potentially important current pathways include stormwater and riverbank erosion. The effects of current releases and these physical site features are expressed in surface sediment concentrations (Panel 10.2-1A).

Known or likely complete historical pathways for PCBs have been identified at 40 sites (Table 10.2-1 and Panels 10.2-1A–C), and include stormwater (38 sites), overland transport and riverbank erosion (6 sites), and overwater releases (1 site).

Current known or likely complete pathways for PCBs have been identified at 18 sites, and include stormwater (16 sites), overland transport (2 sites), riverbank erosion (3 sites,) and groundwater transport (1 site). Current known or likely complete pathways have not been identified for the overwater pathway.

Based on the external loading analysis presented in Section 6.1, stormwater transport is estimated to be the largest current pathway for PCBs to enter the Study Area from lateral sources (i.e., areas adjacent to the Study Area rather than upstream; see Figure 10.2-3).

Numerous upland sites have been identified as being known or likely historical and/or current sources of PCBs. These sites discharge directly to the river or discharge through shared conveyance systems (see Table 4.4-1).

Historical and current known or likely complete pathways for PCBs in stormwater have been identified at several properties associated with former shipyards and sites where transformers were serviced and/or dismantled.

Wastewater discharges are currently regulated primarily through NPDES permits. PCBs are not identified as a monitoring parameter for individual or general NPDES permits (see Tables 4.4-6 and 4.4-7). Wastewater discharges in CSO areas, where wastewater could overflow during CSO events, are regulated through municipal pretreatment permits. PCBs are not identified as a COI at any sites with a pretreatment permit (see Table 4.4-5). Historical wastewater discharges associated with ship building and decommissioning, electrical component manufacturing, and leaks and spills from equipment that used PCBs (e.g., hydraulic oils) are likely, but have not been specifically identified or quantified.

No current known or likely complete PCB overwater pathways have been identified. Current overwater releases may be locally important at sites with continuous waste handling or operational activities, but are considered a minor current pathway overall.

Because of PCBs' hydrophobic nature, groundwater is unlikely to be a significant historical or current pathway for PCB migration into the Study Area. However, PCBs have been detected in groundwater at Triangle Park, which has a current known complete pathway to the river. Triangle Park has been acquired by the University of Portland. A Bona Fide Prospective Purchaser Agreement (BFPPA) was signed with

EPA by the University in December 2008. Under the agreement, EPA is overseeing the work being undertaken by the University to ensure actions are consistent with long-term cleanup remedies for the Superfund site.[11]

Like overland transport, sampling of the riverbank erosion pathway for PCBs is limited. Current known or likely complete PCB riverbank erosion pathways have been identified for EOSM, Gunderson, and Triangle Park. Historical known or likely complete pathways exist for these three sites and for Crawford Street and Willamette Cove, as well.

Overall, atmospheric deposition in the Study Area for PCBs was more significant historically, prior to widespread adoption of controls by many countries on PCB production and usage. Current research suggests that the major source of PCB releases to the atmosphere is an environmental cycling process that involves volatilization from water and/or soil into the atmosphere with subsequent removal via wet/dry deposition and then revolatilization.

Because of their ubiquitous nature, PCBs are found throughout the upriver watershed basins that feed into the Willamette River. Table 4.5-1 lists ECSI sites upstream of the Study Area (between RM 11.8 and the Tualatin River) and associated COIs. Information for these sites is from the DEQ ECSI database. Environmental cleanup of sediments or upland areas have been ordered for some of these properties, indicating that they could be now, or in the past have been, significant sources of PCBs to the Willamette River. Potential pathways are identified if enough information was available in the database. PCBs were identified as COIs for 19 of these sites based on their hazardous substances/waste types. Several of the sites were or are involved in electrical equipment maintenance and repair. Of these 19 sites, PCBs were detected in sampled media at the following 11 sites:

- PGE Willamette River Sediment Investigation (RM 13.1E)
- Rexel/Taylor Electrical Supply (RM 13.2E)
- Portland General Electric Station L (RM 13.4E)
- Zidell Marine Corporation (RM 14W)
- Ross Island (RM 14.6E)
- OHSU - Moody Ave. Units A, B, C (RM 13.7W)
- Heath Oregon Sign Company (RM 14.8E)
- Martin Electric (RM 20.2W)
- Gross Property Disposal Site (RM 25W)

[12] At approximately RM 3, the Columbia River and Multnomah Channel hydraulically influence the flow regime complicating interpretation of load conditions in this area (see Section 3.1.3.3).

- Jeff Lohr Residence (RM 25.5E)
- West Linn Paper Company (RM 26W).

Loading, Fate, and Transport of PCBs

PCB loading, fate, and transport in a typical year for the Study Area is summarized on Figures 10.2-1a-b, 10.2-2, and 10.2-3. Estimates are for current conditions and likely differed historically. Much of the PCB mass in the Study Area, especially in deeper sediments, is attributable to historical loading that occurred under different loading conditions and rates.

Upstream surface water represents the largest estimated current loading term for PCBs to the Study Area (Figures 10.2-1a and 10.2-2), and is associated with both the dissolved and suspended fractions. On an annually averaged basis, the majority of this load occurs during low-flow conditions (Figure 6.1-2) which exist for approximately two-thirds of the year. Surface water samples collected during high-flow consistently exhibited lower concentrations of PCBs than in low-flow samples, indicating that inflow concentrations at high flow rates have greater influence than local effects. Total PCB concentrations in sediments accumulating in upstream borrow pits, which are likely a mixture of upstream bedload and suspended load, are comparable to the upriver bedded sediment background concentrations.

PCB loads in surface water increase between the upstream and downstream boundaries of the Study Area in both the particulate and dissolved fractions, and is in part attributable to quantified external loads (stormwater, atmospheric deposition, and advection through subsurface sediments). Other possible reasons for the increased loading is due to internal fate and transport processes such as sediment resuspension, which have not been quantified. The distribution of total PCBs in surface sediments, sediment trap samples, and the particulate fraction of surface water samples, on both a dry-weight and OC-normalized basis, is presented on Figure 10.2-1b. Surface sediment concentrations across the Study Area are significantly greater than sediment trap sample concentrations, which are greater than surface water suspended solids concentrations. On an OC-normalized basis, the mean surface sediment concentration on a Study Area-wide basis (18.6 mg/kg) is about 1.4 times higher than sediment trap mean concentration (12.9 mg/kg), which, in turn, is about 19 times higher than surface water particulate mean concentration (0.66 mg/kg).

Estimates of current PCB loading via stormwater are approximately half the estimated upstream load, atmospheric deposition directly to the Study Area river surface (is nearly an order of magnitude lower than the upstream surface water load (Figure 10.2-2). PCBs were detected in stormwater in Round 3A and 3B sampling in each land use area sampled (see Section 6.1.2.3 and 10.1.4.1.2). Groundwater advection through subsurface sediments is estimated the least significant of the quantified terms, but is subject to a relatively high degree of uncertainty due to the variability in published organic-carbon partitioning values for PCBs. As discussed in Section 6.1.1.2, bedload into- and out of the Study Area is expected to be low relative to dissolved and particulate surface water loading. PCB volatilization from the water column is relevant for only a small fraction of the less chlorinated PCB congeners and is also expected to be low.

Fate and transport processes internal to the Study Area for total PCBs are shown on Figure 10.2-2. PCB transport to the water column due to pore water advection through surface sediments is only process for which quantitative estimates were developed, and is estimated to be similar in magnitude to the subsurface advective loading. Other internal fate and transport processes are depicted on Figure 10.2-2 on a qualitative basis only. Sediment erosion, deposition, and burial are a function of locally and temporally variable hydrodynamic conditions and the surface sediment mixing rate. PCB partitioning between suspended sediment and surface water depends on the relative concentrations associated with suspended particulate organic carbon and the dissolved surface water fraction, as well as reaction kinetics. The fate of PCBs within the Study Area is also influenced by microbially-facilitated degradation and photolysis. Methanogensis was observed to be occurring in surface sediments in many areas of the Study Area during the RI investigation, reductive dechlorination of PCBs would be expected in anaerobic sediments.

PCB loads from upland groundwater plumes are not expected to be significant and estimates were not generated. Loading from permitted point source discharges were not estimated because PCBs are not regulated and monitored under any active discharge permits within the Study Area. Estimates of PCB loading from upland soil and riverbank erosion also were not assessed due to a paucity of data for riparian soil PCB concentrations and erosion rates.

The total PCB load in surface water increases downstream through the Study Area to RM 4[12] (Figure 10.2-3), the largest PCB stormwater inputs enter the Study Area between RM 3 and 4. As described in Section 6.1.2, the estimated load (1 kg/yr) to this reach is largely from a non-representative (unique) site (Outfall WR-384) and exceeds the next highest stormwater load, between RM 8 and 9, by a factor of 10.

Atmospheric deposition is estimated to contribute a total PCB load approximately one-third that of stormwater at the Study Area scale. Deposition loading to the water surface varies only as a function of water surface area by river mile.The estimated current PCB loads from the subsurface and surface sediments mirror the patterns of subsurface PCB sediment contamination (Panel 10.2-1B), with the highest loads between RM 8 and 9.

No current known or likely complete PCB overwater pathways have been identified. Current overwater releases may be locally important at sites with continuous waste handling or operational activities, but are considered a minor current pathway overall.

[12] At approximately RM 3, the Columbia River and Multnomah Channel hydraulically influence the flow regime complicating interpretation of load conditions in this area (see Section 3.1.3.3).

PCB CSM Summary

PCBs are no longer produced; however, they are common in the environment due to widespread historical sources, such as dielectric fluids in transformers, hydraulic oils, lubricants, and additives, and current sources such as waste materials from scrap metal recycling and the repair of ships and heavy equipment. PCBs are detected in Portland Harbor surface and subsurface sediments, other abiotic media (such as surface water), and fish and shellfish tissues. PCB concentrations in sediments across much of the Study Area are comparable to upriver background levels. In contrast, a number of distinct subareas of the Study Area exhibit surface and/or subsurface sediment total PCB concentrations that greatly exceed these levels. With minor exceptions, these subareas are located in nearshore (outside of the navigation channel) and off-channel (off the mainstem of the river, such as Swan Island Lagoon) areas that are both more quiescent and proximal to likely or known historical sources. PCB composition (homolog patterns) shows variations between many of the subareas, further suggesting localized sources. The largest areas of elevated PCBs in sediment include the areas offshore of the former Albina Shipyard at RM 11.3, Gunderson, Swan Island Lagoon, International Slip, RM 4E (International Terminal), and EOSM.

In most of the subareas with elevated PCB sediment concentrations, and throughout the Study Area generally, subsurface PCB concentrations exceed surface levels, indicating greater inputs or releases historically that have been reduced or eliminated over time. Small-home-range fish and shellfish tissue samples collocated with these subareas generally exhibit elevated levels, indicating some ongoing exposure and biological uptake. The localized long-term accumulation of sediments (and PCBs) in the sediment column, as well as the physical site characteristics (e.g., time-series bathymetric changes) and HST modeling, indicate that most of these subareas are depositional/stable over time. Empirical data (time-series bathymetry, sediment-profile data, and limited radioisotope cores) further suggest that many of the nearshore areas have low long-term net sedimentation rates and the surface sediment layer is well-mixed; this likely contributes to the persistence of relatively elevated surface sediment levels. However, with effective source control, surface sediment PCB concentrations in the physically stable areas of the harbor will likely continue to decrease over time due to various attenuation processes and the higher subsurface PCB levels will likely remain isolated from biological receptors.

One noteworthy exception to these general patterns is the elevated PCB subarea at RM 11.3E. Though there are exceptions, several sampling points in this area exhibit higher surface sediment than subsurface levels along the eastern nearshore area and adjacent channel edge. The nearshore sediment PCB distribution, as well as the collocated surface water and sediment trap data, suggest a local, recent input and/or redistribution of PCBs historically released into this area and present in the sediments. Data from recent sediment studies in the RM 11E area, provided in Appendix H, indicate that ship traffic and recent maintenance dredging at the Glacier NW dock (RM 11.3E) and the CDL Pacific Grain dock (RM 11.4E) have resulted in resuspension, exposure, and redistribution of PCB contaminated sediments in this nearshore area.

Also, the federal navigational channel in this relatively dynamic segment of the Study Area reach is subject to high flows and both short- and long-term sediment scour. While the highly elevated PCB subareas in the Study Area appear to result from releases from specific localized sources (both historical and/or current), PCBs also enter the Study Area from more general sources, such as private and public stormwater and sewer outfalls, and sources upstream of the Study Area in the Willamette River. Also, not all sources for all areas of elevated concentrations have been identified. Harbor-wide loading estimates indicate that the highest current external inputs to the Study Area are from upstream surface water and, to a lesser degree, stormwater runoff and atmospheric deposition within the Study Area. The same estimates indicate that the mass flux of PCBs in surface water (dissolved and particulate) exiting the Study Area at RM 2 and at the Multnomah Channel entrance exceed the estimated fluxes entering the Study Area from all quantified external loading terms. This suggests an internal mass transfer of PCBs from bedded sediment to the water column, likely through sediment resuspension.

Overall, PCBs are the most significant risk-posing contaminant in Portland Harbor. The highest human health risks from exposure to PCB concentrations were associated with the fish consumption pathway, for which PCBs contribute approximately 93 percent of the cumulative cancer risk for whole-body consumption and approximately 97 percent of the cumulative risk for fillet consumption, on a Study Area-wide basis.

Total PCBs pose significant risk to mink, river otter, and spotted sandpiper, and low risk to osprey, bald eagle, sculpin, and smallmouth bass. PCBs were identified as one of the primary contaminants in sediment likely to pose potentially unacceptable risk to the benthic community or populations.

The relationships between tissue body burdens and abiotic concentrations across the Study Area are a primary focus of the fate and transport modeling to be conducted as part of the FS. Elevated levels of PCBs in tissue are generally correlated with elevated levels of sediment contamination, surface water contamination, and sediment trap contamination. Furthermore, elevated surface water contamination seems to be associated with elevated sediment contamination. The reasons for this are complex. In some cases, surface water contamination may be associated with stormwater, and in other cases it may be associated with sediment. Indications are that PCB levels in surface sediments in most areas are decreasing over time. The rate of this improvement is a function of localized net sedimentation rates, erosion potential, surface sediment mixing rates, degradation rates in aerobic and anaerobic sediments, and source control actions.

10.1.2.4.2 TCDD

10.1.3 Risk Assessment – Pathways, Exposure, and Receptors

The following subsections briefly summarize the major findings of the BHHRA (Section 8 and Appendix F) and BERA (Section 9 and Appendix G) to the extent necessary for purposes of the CSM, including summaries of human use and ecology of the LWR. Summaries of risk and identified receptors for each IC are provided in Section 10.2.

10.1.3.1 BHHRA

10.1.3.1.1 CSM

Information on human uses of the river, its shorelines, and resources, as detailed in Section 3.2.5, was used to determine potential receptor populations for the BHHRA. Figure 8.2-1, the BHHRA CSM, lists the human receptor populations.

People interact with the river in a number of ways. Portland Harbor is a major industrial water corridor and working harbor, and the majority of the Study Area waterfront is currently zoned for industrial land use (City of Portland 2006b). Worker activities that may include contact with sediments and surface water at industrial and commercial facilities in the Study Area are somewhat limited due to the sparse beach areas and high docks associated with most of the industrial and port facilities. In the Study Area, some commercial diving occurs, although the practice of using dry suits would clearly limit exposure via sediment ingestion or dermal contact.

The Study Area also contains some natural areas and provides recreational opportunities, both on the water and along the riverbanks, including boat ramps, beaches, and waterfront parks. Recreational/non-commercial fishing is conducted throughout the LWR basin and in the Study Area, both by boaters and from shore. Non-tribal and Native American anglers may catch and eat fish from the LWR. For Native American anglers, the Willamette River provides a ceremonial and subsistence fishery for Pacific lamprey and spring Chinook salmon. The extent to which commercial fishing occurs within the Study Area is not known, but it is thought to be negligible.

In theory, shellfish consumption could occur throughout the Study Area wherever shellfish are found. However, it is not known to what extent shellfish consumption occurs by recreational fishers or transients. The Linnton Community Center project (Wagner 2004, pers. comm.) stated that some transients reported eating clams and crayfish; however, many of the individuals indicated that they were in the area temporarily, move from location to location frequently, or have variable diets based on what is easily available. The ODHS occasionally receives calls from citizens who are interested in harvesting crayfish from local waters and are interested in fish advisory information. According to a member of the Oregon Bass and Panfish club, crayfish traps are placed in the Portland Harbor Superfund Site boundaries and collected for bait and possibly consumption (ATSDR 2006). Even if collection does occur within the

Study Area, it is not known whether those crayfish are consumed by humans or used as bait. The shellfish consumption pathway was evaluated at the direction of EPA.

Based on this site use information, the following potentially complete exposure pathways were quantitatively evaluated in the BHHRA:

- Direct exposure to (i.e., ingestion of and dermal contact with) beach sediment
- Direct exposure to in-water sediment
- Direct exposure to surface water
- Direct exposure to groundwater seeps
- Ingestion of fish
- Ingestion of shellfish.
- Infant consumption of human milk.

A summary of the estimated cancer risks and non-cancer hazards (expressed as an HI) for each of these potential exposure pathways is provided below. The risks to infants through consumption of human milk are presented with the mother's potential exposure pathway. While some of these exposure pathways discussed below result in an estimated cancer risk greater than 1×10^{-6}, the exposure scenarios with estimated cancer risks exceeding 1×10^{-4} or an estimated HI greater than 1 are fish and shellfish ingestion throughout the Study Area, exposure to untreated surface water as a hypothetical drinking water source at two exposure areas, and direct exposure to in-water sediment for two half-river-mile segments.

Direct Exposure to Beach Sediment

None of the beach sediment exposure scenarios resulted in cancer risks above the EPA target range (i.e., greater than 10^{-4}) or HIs greater than 1. For CT assumptions, dockside worker, child recreational beach user, combined adult/child recreational beach user, and tribal fisher scenarios resulted in cancer risks above 1×10^{-6}. The RME scenarios for exposure to beach sediment resulting in cumulative cancer risks above 1×10^{-6} include: dockside worker, adult and child recreational beach user, tribal fisher, low frequency fisher, and high frequency fisher.

Direct Exposure to In-water Sediment

None of the in-water sediment exposure scenarios based on CT assumptions resulted in cancer risks above the EPA target range (i.e., greater than 10^{-4}) or HIs greater than 1; the tribal fisher and breastfeeding infant CT scenarios had cancer risks above 1×10^{-6}. For the RME scenarios, cumulative cancer risks were greater than 1×10^{-6} but were below 1×10^{-4}, with the exception of cancer risks above 1×10^{-4} for in-water sediment exposures to a breastfeeding infant (at RM 7W) and to a tribal fisher (at RM 6W and 7W). RM 7W also presents a cumulative HI greater than 1 for the tribal fisher, high frequency fisher, and breastfeeding infant RME scenarios.

Direct Exposure to Surface Water

None of the surface water exposure scenarios (i.e., transients, divers, and adult and child recreational users) resulted in cancer risks above the EPA target range (i.e., greater than 10^{-4}) or HIs greater than 1. The only scenarios resulting in cumulative cancer risks greater than 1 x 10^{-6} were the diver in wet suit and the diver in dry suit RME scenarios at RM 6W.

For hypothetical exposure to untreated surface water used as a domestic water source by future residents, both the CT and RME scenarios resulted in cancer risks above 1 x 10^{-4} at RM 6.1. None of the other locations resulted in cancer risks above the EPA target range (i.e., greater than 10^{-4}). The child RME scenario for hypothetical exposure to untreated surface water as a domestic water source was the only scenario with a HI that exceeded 1, which occurred at RM 8.5.

Direct Exposure to Groundwater Seep

Risks from direct contact with groundwater seeps were evaluated for exposure by a transient for one exposure point. The transient exposure scenario did not result in cancer risks greater than 1 x 10^{-6} or HIs greater than 1.

Ingestion of Fish

The exposure scenarios evaluated for ingestion of fish in the BHHRA resulted in ranges of estimated cancer risks and HIs. Many of the exposure scenarios resulted in cancer risks greater than 10^{-4} and HIs greater than 1. The highest cancer risks and HIs were associated with the assumptions of the highest fish ingestion rate used in the BHHRA (142 g/day) and a diet consisting of only whole-body carp.

Ingestion of Shellfish

The exposure scenarios evaluated for ingestion of shellfish in the BHHRA resulted in ranges of estimated cancer risks and HIs. Some of the exposure scenarios resulted in cancer risks greater than 10^{-4} and HIs greater than 1. The highest cancer risks and HIs were associated with the assumptions of the highest shellfish ingestion rate used in the BHHRA (18 g/day) and a diet consisting of only non-depurated clams. Although the harvest and possession of Asian clams, which is the clam species that was found in the LWR during sampling events, is illegal in the State of Oregon (OAR 635–056–0050), EPA has stated that it has information that harvesting occurs. The extent to which ingestion of shellfish may occur within the Study Area, both currently and in the future, is unknown.

10.1.3.1.2 BHHRA Summary

The primary exposure pathway accounting for the majority of risk for human health in Portland Harbor is ingestion of fish. PCBs are the primary contributor to risk for fish consumption, and dioxins are a secondary risk contributor for fish consumption of both whole body and fillet tissue diets. PCBs and dioxins/furans both resulted in cancer risks greater than 1 x 10^{-4} and HQs greater than 1 for fish ingestion for both localized and Study Area-wide exposures. PCBs and dioxins/furans contribute approximately 98 percent of the cumulative cancer risk for whole-body fish ingestion and approximately 99 percent of the cumulative cancer risk for fillet fish ingestion on a Study Area-wide basis. The contribution of contaminants to the cumulative cancer risks varies on a localized basis. Other Indicator contaminants that resulted in cancer risks greater than 1 x 10^{-4} or HQs greater than 1 on a limited spatial scale and/or for a specific exposure scenario included cPAHs, DDx, BEHP, arsenic, and zinc.

At the direction of EPA, the BHHRA was developed to provide a health-protective assessment of risks associated with contaminants present at the Site. To derive risk estimates in the BHHRA, exposure parameters based on health-protective assumptions were multiplied together, resulting in compounded uncertainty that may underestimate or overestimate the actual risks that may exist within the Study Area (see Section 6 of Appendix F for an analysis of the uncertainties associated with the BHHRA). The results of the BHHRA should be weighed in a measured and informed fashion in light of the health-protective assumptions. Moreover, the contribution of background sources is an important consideration in risk management decisions. On a regional scale, fish consumption results in risk estimates exceeding cumulative risks of 1 x 10^{-4} or HI of 1 based on fish tissue data collected from the Willamette and Columbia rivers outside of the Study Area. However, concentrations are higher within the Study Area than in the regional tissue. Regional efforts are underway to reduce fish tissue concentrations. Sources contributing to regional tissue concentrations are unknown.

10.1.3.2 Site Ecology and Baseline Ecological Risk Assessment Findings

Details on the Study Area's ecology, provided in the BERA (Appendix G) and Section 3.1.6, are summarized here, followed by a summary of the findings of the BERA. The BERA is summarized in more detail in Section 9. The majority of the Study Area is industrialized, with modified shoreline and nearshore areas (e.g., wharfs, piers extending out toward the channel, bulkheads, and riprap-armored banks). The federal navigation channel, authorized to –43 ft and currently maintained to –40 ft CRD, has little habitat diversity. However, some segments of the Study Area are more complex, with small embayments, shallow water areas, gently sloped beaches, localized small wood accumulations, and less shoreline development, providing some habitat for a suite of local fauna. By area, the major habitat in the Study Area is associated with the river bottom or water column. Riparian, shallow-water, and vegetated habitats are limited to the nearshore area or shoreline, and are much less extensive. Although limited in area, these habitats provide important ecological services, such as refuge for juvenile fish species, importation of organic material and nutrients from terrestrial and shallow-water vegetation, breeding for amphibians (in low velocity areas), foraging for migratory waterfowl and shorebirds, and where unarmored, contribution of sediment that affects the character and stability of benthic habitats.

The organisms that use the LWR include invertebrates, fishes, birds, mammals, amphibians, reptiles, and aquatic plants. Each group contributes to the ecological function of the river based on trophic level, abundance, biomass, and interaction with the physical-chemical environment and other species. Riverine invertebrates are predominantly benthic, living on or in such substrates as fine-grained sediments, gravel and cobble, plant roots, or large woody debris. Much of the infaunal invertebrate community within the LWR feeds on and processes organic material imported from upriver areas.

The LWR is an important migration corridor for anadromous fish, such as salmon and lamprey, and provides habitat for numerous resident fish species (more than 40 species have been collected in many historical and recent studies) that represent four feeding guilds: herbivores, invertivores (either from the water column or bottom habitats), piscivores, and detritivores. A number of species are omnivores[13] and utilize multiple food types. The type of riverbank present in the Study Area influences the fish species occurrence and use of a given area.

Limited suitable habitat for amphibians and reptiles is present in the LWR. Amphibians prefer undisturbed, shallow-water areas with adjoining ephemeral wetlands and emergent vegetation. Reptiles prefer shallow, quiescent aquatic areas and wet vegetated terrestrial habitats. Current conditions in the LWR prevent the widespread development of dense, submerged, floating-leaved, and emergent aquatic plant communities along the riverbanks because of high turbidity, few quiescent areas, and the presence of riprap and other bank modifications.

For semi-aquatic mammals that depend on shoreline plant cover, habitat in the Study Area is limited because of past human modification of riparian habitats. The upland environment near the LWR is primarily urban, with fragmented areas of riparian forest, wetlands, and associated upland forests. Historical development and filling of channels and wetlands has left only small strips or isolated pockets of riparian wildlife habitat.

Mink and river otter, both semi-aquatic species, were evaluated in the BERA. The Study Area offers at least marginally suitable habitat, and both species have been collected nearby (Elliott et al. 1999; Henny et al. 1996). For birds, the fragmentation of habitat may not be as critical as for mammals. Numerous aquatic and shorebird species, such as cormorants and spotted sandpipers, use the habitats, where available, in the Study Area.

Based on the ecology of the LWR, multiple complete exposure pathways were evaluated for risk to various ecological receptor groups in the BERA (Section 9). The exposure pathways evaluated in the BERA were identified based on behaviors and characteristics of selected ecological receptors, or were required by EPA for evaluation in the BERA. The following complete and significant exposure pathways were quantitatively evaluated in the BERA using multiple lines of evidence:

- **Benthic invertebrates –** Direct contact with sediment and surface water, ingestion of biota and sediment, and direct contact with shallow TZW

- **Fish –** Direct contact with surface water, direct contact with sediment (for benthic fish receptors), ingestion of biota, incidental ingestion of sediment, and direct contact with shallow TZW (for benthic fish receptors)
- **Birds and mammals –** Ingestion of biota and incidental ingestion of sediment
- **Amphibians and aquatic plants –** Direct contact with surface water and shallow TZW.

In total, 89 contaminants (as individual chemicals, intermediate sums, or totals) were identified as posing potentially unacceptable ecological risks. Potentially unacceptable ecological risks were identified from metals, TBT, PAHs and other SVOCs (including chlorinated benzenes, benzyl alcohol, dibenzofurans, carbazole, phenols, and phthalates), PCBs, dioxins and furans, DDx and other pesticides, and VOCs. The risk of ecologically significant adverse effects on populations or communities of ecological receptors in the Study Area is greatest from four groups of chemical mixtures: PAHs, PCBs, dioxins and furans, and total DDx.

The BERA found potentially unacceptable benthic risks in about 7 percent of the Study Area based on all lines of evidence. The COPCs in sediment that pose potentially unacceptable risk to the benthic community or populations are PAHs, PCBs, and DDx compounds. The phenolic compound 4-methylphenol may also be contributing to unacceptable benthic community risk. Widely distributed throughout the Study Area, this contaminant is found in both contaminated and otherwise uncontaminated areas. With a half-life on the order of days, its presence suggests ongoing sources. Whether and to what extent the source is legacy contamination is not known.

PCB HQs ≥ 1 occurred throughout the Study Area for river otter, mink, spotted sandpiper, bald eagle, and osprey, indicating possible population-level effects. The potential for adverse effects in fish due to exposure to total PCBs is low based on limited extent and frequency of TRV exceedances and the likelihood that uncertainties contribute to overestimates of risks. The combined toxicity of dioxins/furans and dioxin-like PCBs expressed as TEQ poses risk of reduced reproductive success in mink, river otter, sandpiper, bald eagle, and osprey. PCBs are responsible for the majority of total TEQ exposure, but the dioxin/furan TEQ also exceeds its TRV in some locations of the Study Area.

Total DDx HQs ≥ 1 occurred for sculpin for certain LOEs and for spotted sandpiper. The weight of evidence indicates the DDx likely poses negligible risk to populations of these receptors because of the low magnitude and limited frequency of exceedances and likelihood that uncertainties contribute to overestimates of risks. For many COIs, the available exposure and effects data preclude a quantitative risk evaluation. These COIs have nonetheless been identified as posing potentially unacceptable risk.

10.2 CONCLUSIONS